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INVESTIGATION OF POTENTIAL WASTE INSULATING MATERIAL PROPERTIES WITH DIFFERENT HEAT TRANSFER FLUID FOR THERMAL STORAGE APPLICATION

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ABSTRACT

Though thermal energy storage (TES) is well developed hugely in most of the solar power generation plant, it is less growth in implementing a modular type of TES in a solar plant, e.g. Solar dish/Stirling engine application. The main issue in designing the TES system is its thermal capacity of storage materials, e.g. insulator. This study is focusing on the potential waste material as an insulator for thermal energy storage applications. The insulator usage is to reduce the heat transfer between two medium and the capability is measured by its resistance to heat flow. It is needed to obtain optimal material to energy conversion at the same time reduce the waste generation. Therefore, a small-scale experimental testing of natural cooling process of an insulated tank within a confined room without any forced cooling system, e.g. fan. The testing is repeated by changing the insulator using the potential waste material from natural and industrial waste and also by changing the heat transfer fluid (HTF). The analysis is performed on the relationship between heat loss and the reserved period by the insulator. The results indicate the percentage of period of the insulated tank withstands the heat compared to non-insulated tank, e.g. foam reserved the period of 333% more than non-insulated tank to withstand the heat transfer of cooking oil to the surrounding. The paper finally justifies the most potential waste material as an insulator in different heat transfer fluid.

***Keywords*:**Thermal Storage, Waste Material, Insulator

INTRODUCTION

Todays, a lot of countries already take actions on implementing the green development. Green development not only focusing on the renewable energy but also in utilising the waste products that been produced by industrialisation or naturally. As this is also a concern over the green future of a country.

Researchers have classified the materials for TES since 1983. Thenceforth, it is encourage that renewable energy researcher in countries take fundamental role in preparing to replace fossil fuel towards novel fuel sources, which are not only clean, but also renewable and safe (Solangi et al., 2010).

Solar energy is one of the cleanest energy resources that do not compromise or add to the global warming (Solangi et al., 2010). Usually four elements are required in solar plant: concentrator, receiver, power conversion device, and transport or storage system. The important component in the power plant is thermal storage. However, it is also one of the less developed in small scale size (Gil et al., 2010).

TES is used to prolong the usage of power generation during the off-peak period, e.g winter and night. Besides that, TES is used to normalised the working temperature of the energy conversion device. Energy storage systems become more and more important to balance the difference and reduce the mismatch between supply and demand (Wang, 2012).

MATERIALS AND METHODS

Insulating Materials

For TES development, instead of the temperature difference between two locations and the heat transfer fluid used as the medium of transferring the energy conservation, other relevant variable is the materials involved in the transfer process. The thermal storage capacity is defined as the ability of a material to stand up heat quantities in a temperature gradient.

In TES development, there are a variation of materials can be used as an insulator in order to absorb heat. The insulator capability is measured by its R-value, which was the resistance to heat flow. The higher the number, the more blocking capacity or insulating it provides. Table 1summarized the insulating capabilities, densities and thermal conductivities of materials used in this study.

Table 1. Thermal properties of natural materials.

Material	Insulating Capability (R-value) K.m^2/W	Density, ρ kg/m^3	Thermal conductivity, k W/m.K
Newspaper	0.52-0.7	930	0.18
Coconut husk	n.a	63-70	0.047
Rubber	1.23	1100	0.13
Foam	1.23-1.41	30-150	0.025-0.035
Wood dust	0.12 (hard) 0.25 (soft)	500-800	0.147
Wire mesh	3.8-4.1	7850-7950	0.22-0.65

Technically in designing a thermal energy storage is required high energy density in the storage material, good heat transfer between HTF and storage medium, mechanical and chemical stability of storage material, compatibility between HTF, heat exchanger and/or storage medium, complete reversibility of a number of charging/discharging cycles, low thermal losses, and ease of control (Gil et al., 2010).

As Bazmi et al. stated renewable energy provides an effective option for the provision of energy resource for industrialization; thus it is needed to obtain optimal material to energy conversion at the same time minimize the waste generation and usage of by-products. This scenario leads towards the usage of waste materials in TES applications as listed in Table 1.

A material used in TES must fulfill the thermal properties; obtained phase change temperature fitted to the TES application, has high change of enthalpy near temperature of use and high thermal conductivity in both liquid and solid phases. In the other hand, Gil suggested to used a material that is low cost, good thermal conductivities, ease during handling and have good structural strength. Hence using the waste materials as insulators, it is not only reduce the price but also reduce the pollution.

Heat Transfer Fluid (HTF)

HTF suppliers have developed a variety of organic and water-based fluids to meet the operating needs of various applications. Theoretically, heat is transfer energy from the high temperature object to the low temperature object (Cengel, 2006). As the need of energy conservation is increased, the importance of the HTF continue to grow. In industrial and residential applications, the usage of HTF is becoming more prominent in order to improve the efficient usage of energy.

In 2005, Canbazoglu tested an open-loop passive solar water-heating system with storage tank using water as the HTF. As in his study the midpoint temperature at the storage is observed between the ranges of 32^0C to 65^0C. The temperature decreased regularly by day until the temperature of PCM after the intensity of solar radiation decreased and then the value was constant at 45^0C in a range of time approximately ten hours during the night without hot water supply.

Mawire et al. has been using oil in the glass tube TES system and its thermal performance is evaluated. In his study, he presented the results of energy and exergy charging rates during the experiments at temperatures of 200^0C, 250^0C, and 300^0C. The results indicate an optimal charging temperature when exceeded the usage and the thermal performance due to increased heat losses. Mawire repeats the same experiment but using oil-packed-bed TES system.

Selection of a HTF is based on the consideration of the efficiency at which the fluid can transfer heat away or toward a specific application. Selected fluid usually having maximum bulk temperature range marginally above the design operating temperature of the fluid can significantly extend the fluid life. As energy efficiency is more prominent, so the HTF will acts in providing practical solutions. Nevertheless, it is particularly essential if HTF in an application can utilize heat in more productive methods.

Thermal Study of Materials

Insulating capability is measured with thermal conductivity (k). Low thermal conductivity is equivalent to high insulating capability (R-value). Thermal conductivity, k represents how well a material conducts heat. In thermal engineering, other important properties of insulating materials are product density (ρ) and specific heat capacity (c). The product of density and specific heat is the heat capacity of a material. The ratio of the thermal conductivity and heat capacity defined the thermal diffusivity.

$$\alpha = \frac{k}{\rho c} \tag{1}$$

Thermal diffusivity measures on how fast the heat diffuses through a material. Based on Cengel, the larger the thermal diffusivity of a material, the heat is mostly absorbed by the material and a small amount of heat is conducted further. A material has a high thermal conductivity or low heat capacity will have a high thermal diffusivity.

In designing thermal energy storage, the material used for the insulator must have low k-value so that the HTF will results in low heat loss. Based on the Newton's Law of Cooling, the rate heat loss to the surroundings is proportional to the temperature excess above the surroundings.

$$\frac{dQ}{dt}=k\ (T_1-T_2) \tag{2}$$

Based on the equation (2), can be viewed as define equation of thermal conductivity. High values of thermal conductivity indicate that the material is a good heat conductor, and a low value indicates that the material is an insulator. By considering steady heat conduction,

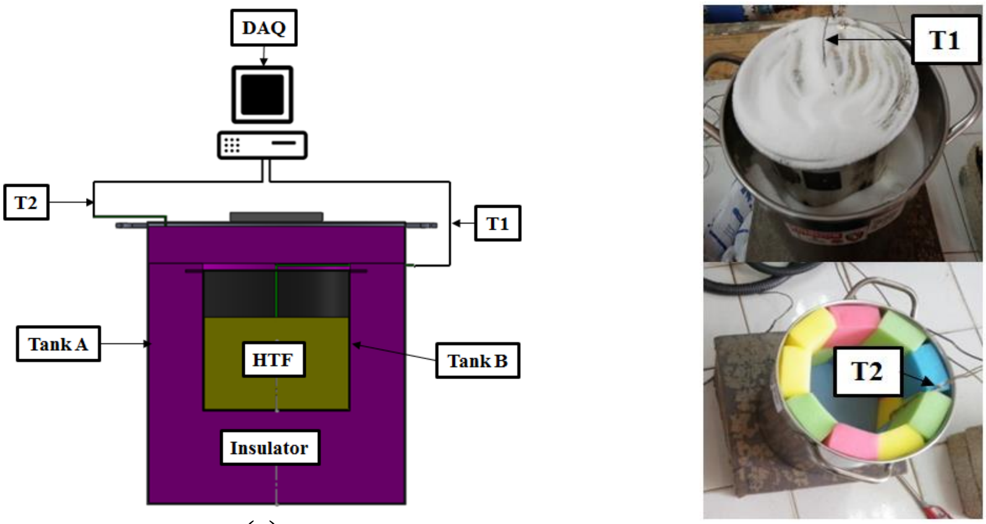
$$\dot{Q}= -kA\frac{dT}{dx} \tag{3}$$

Based on Fourier's law of heat conduction conclude that the rate of heat conduction through a plane layer is proportional to the temperature difference across the layer and the heat transfer area, but is inversely proportional to the thickness of the layer. Here, dT/dx is the temperature gradient, which is the slope of the temperature curve on T-x diagram (the rate of change of T with x, e.g. time), at location x.

Experimental Testing Setup

A small-scale storage tank is developed for the insulation testing. The storage tank is going through natural cooling process in a confined room. By the end of the findings will justify the most potential waste material as an insulator in different HTF based on the non-insulated condition.

The experiment can be outlined in the subsequent way in a confined room without any force cooling process. Firstly, a cylindrical container, Tank A, is filled with the insulator material with thickness of 40mm. Thermocouples are placed at the position illustrated in Figure 1. Then a litre of HTF; water or cooking oil, is prepared in a cylindrical container, Tank B. The HTF is heated and maintained at 100^0C for water and 300^0C for cooking oil. Then Tank B is placed in the Tank A. As described in the Figures1, the insulator surrounded the Tank B compactly.



(a) (b)

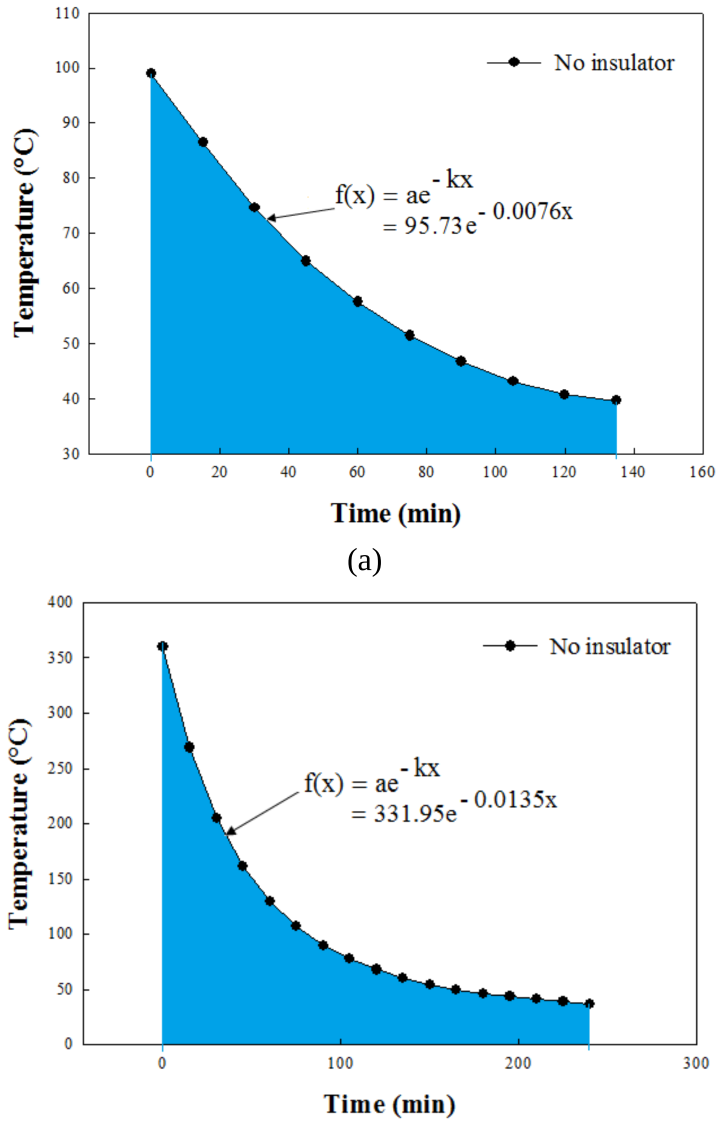
Figure 1. Experimental setup (a)section view and (b)actual conditions.

A computer for data acquisition system was setup to measure the temperatures and accumulate the data. The HTF temperature, T1, measurement point was set in the middle of the container, Tank B, and the insulating material temperature, T2, was set at a point between Tank A and Tank B.The method of testing the storage materials was based on monitoring the temperature and time of the experimental period. The testing is measured until T1 reached 40^0C. The measurements of temperature and time are reported in plotted graphs.

This method is developed for the study on diffusion of materials act as an insulator in thermal storage system. This process was setup also based on the combination testing done by Canbazoglu, Adinberg and Royon. Yet the situation is simplified because the materials as insulator is solid and the temperature measurement points are focused only in containers of HTF and insulator. Visibly, the experiment was designed to validate the theoretical approach on heat losses and reserved period, not the structure of the materials.

RESULTS & DISCUSSION

The distribution of temperature over time during testing are shown in Figure 2(a) and 2(b). The figures show the heat of insulators decay decreased and cooling towards the temperature of 40^0C. The areas under the graphs are the reserved period of the non-insulated tank using a litre of water (Figure 2(a)) and oil (Figure 2(b)) as HTF respectively.



(a)

(b)

Figure2.Effect of temperature at different time with (a)water HTF and (b)oil HTF.

As shown in Figure 2 pattern is exponential decay and the exponential function can be expressed as:

$$f(x)=ae^{-kx} \tag{4}$$

where,

x: time

k: thermal conductivity(k = 0.0076 and 0.0135)

a: mean temperature (a = 95.73 and 331.95)

(-) sign: cooling process

The results from experiments proved the experimental undergoes process of cooling. The experiment is repeated using different insulators, which were results in different k-values. Then, the k-values are pointed in Figure 3.

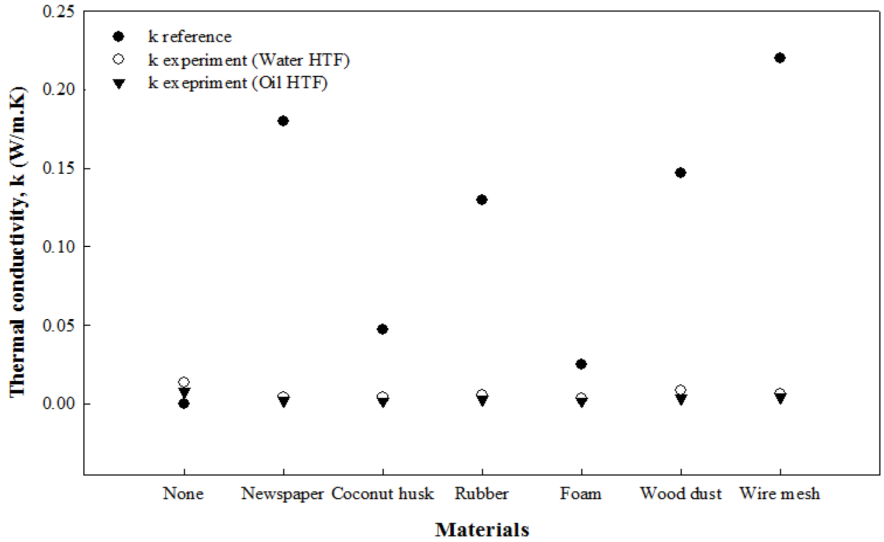


Figure 3.Effect of thermal conductivity,k at different materials.

The effect of thermal conductivity,k at different insulator material is shown in Figure 3. From the figure, the values for water and oil testing result nearly the same, but there are differences between the experimental and reference values are due to the experimental setup of the containers did not reach the level of vacuum. Then, based on the results of time, the overall percentage of the reserved period of the insulator is calculated by:

$$\text{Percentage of Reserved Period} = \frac{t_{\text{insulator}}}{t_{\text{non-insulator}}} \text{ x } 100\% \tag{5}$$

The reserved period for the insulators is shown in Figure 4. The results show the percentage of the reserved period for potential waste insulating materials in water and oil testing. This figure also showed the value differences between an insulated tank and non-insulated tanks.

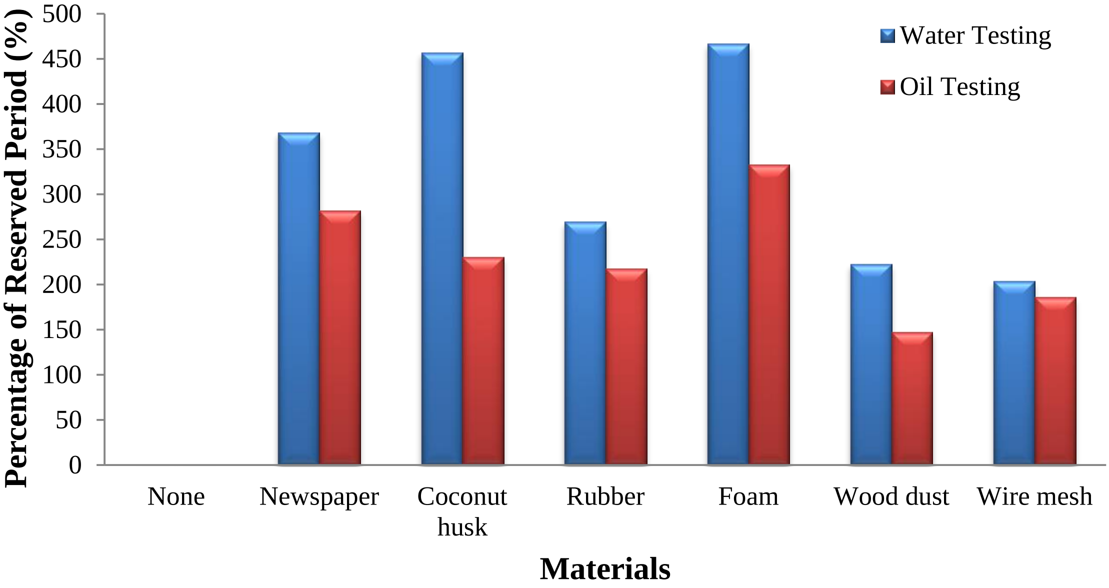


Figure 4.Effect of percentage of the reserved period at different potential waste materials.

The highest percentage of the reserved period for the insulated tank to withstand the heat compared to non-insulated for water as HTF is foam. This is followed by coconut husk, newspaper, rubber, wood dust and wire mesh. The percentages of the reserved period are 467%, 457%, 369%, 270%, 223% and 204% respectively, better than non-insulated tank.

For the oil HTF, the longest reserved period insulator is foam with the percentage of 333%. This is followed by newspaper, coconut husk, rubber, wire mesh and wood dust which given the value of 282%, 231%, 218%, 186% and 147% respectively.

It is proven that with the presence of insulator, the temperature of HTF is maintained longer than the HTF tank without insulator. Based on Canbazoglu and Royon, a suitable material is the one with a low thermal conductivity with low heat loss and high insulating capability.

CONCLUSION

Development of new storage system is one of the engineering understandings in heat transfer field. Although insulation system could be increase the reserved period easily, choosing the insulator materials are also expensive based on its application. In this study, the waste materials could also increase the reserved period of the HTF. With the point of reference of the non-insulated tank, the percentage of insulator reserved period can be calculated.

For future development, based on the results the potential waste insulator could be combine and arrange surrounded the HTF tank for the insulation test. Conducting this experiment could further prove that combination insulator also can increase the insulation system reserved period.

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